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STUDY OF CIRCULATING COAL FLUIDIZED BOILERS

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ABSTRACT : **In the days of modernization, industrialization, technological world we find out a new method of steam production with help of coal. This state of act systems are manufactured over a range of 500 TPH.This boilers are highly efficient, multi coal firing capacity, less emission of so2 and nox gases, utilize high ignite cokes, petcoats,washery rejects. This survey paper is intended to comprehensively give an account of domain knowledge related to CFBC boiler. The authors touch upon the design changes which are introduced in the component levels in order to ease the operation, enhance the performance and to meet the regulatory compliance. In addition, salient correlations related to hydrodynamics, heat transfer and combustion are narrated to facilitate the control and system engineers to develop mathematical models using conservation of mass, energy and momentum equations.**

I. INTRODUCTION

Lack of coal and quality of coal has been degraded due to which it give rise to Fluidized coal based boilers. The fuel and the cold fly ash recirculated to the fluidised bed is well mixed with the hot bed material resulting in a uniform temperature distribution in the bed. This is achieved by a higher turbulence caused by introducing fluidising air in smaller bed dimensions.

Unlike the Bubbling AFBC boilers the erosion prone submerged heating surfaces are dispensed with. The recirculated cold fly ash takes over the cooling of the fluidised bed. It is in the convection pass that the heat taken is transferred to the convectional heating surfaces. The boiler has a tower-type arrangement.

The first boiler pass is formed by water-cooled, gas-tight membrane tube walls. They are part of the evaporator system and are designed for natural circulation.

The lower section of the first boiler pass consists of the combustion chamber with the fluidised bed and the freeboard above. The upper section is made up of a convection heating surfaces namely super heater, evaporator and part economiser. This first boiler pass is top supported allowing easy expansion downwards.

The second boiler pass has remaining part of the economiser heating surface and the tubular air heater. The elutriated fly ash is separated from the flue gases in cyclone separators located between the boiler first and second pass, at a temperature of around 400^{O}C. It is recirculated into the combustion chamber via a siphon system which serves as a seal.

The ash from the fluidised bed, the cyclone and the ESP is conveyed pneumatically to the main ash silo, keeping the plant clean of ash.

The boiler is designed with fluidising velocities up to 4.5m/s, generating a high turbulence and resulting in a good mixing of hot bed material with fuel and recirculated fly ash.

The height of the bed is kept constant by removal of the produced bed ash as a function of the differential pressure between the airbox and freeboard.

The amply dimensioned freeboard height guarantees a mean residence time of flue gases of at least 4 seconds. The correspondingly long residence time of elutriated fuel particles has its decisive share in the high degree of combustion and desulphurization efficiency.

The recirculated fly ash quantity is adjusted to maintain a temperature of the fluidised bed of about 850^{O}C.

This quantity of fly ash recirculation suffices to ensure the burn-out of fines and the capture of sulphur in the freeboard at optimal consumption of limestone.

The heat transfer is higher for CFBC than BFB boilers and the heat transfer is mainly due to particle convection. The combustion efficiency in CFBC is increased due to the recirculation of solid particles. Limestone added to CFBC boiler reduces the Sox and NOx. It is comparatively less than BFBC boilers.

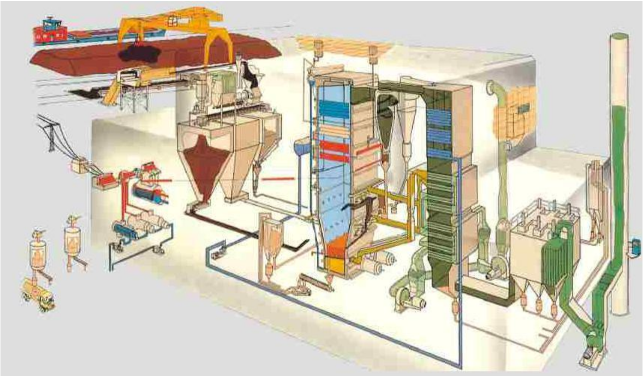
There are several reasons why CFBC technology is well suited. Some of them are: fuel flexibility, ability to burn low grade coal, good emission control of SO_2, NOx, better efficiency, no need of fuel pulverization, easy startup and shut down operation and is less corrosive. Instead of coal, M. Miccio, F. Miccio stated that liquid fuels can also be used for the combustion in CFBC boilers. Variables like Bed height, bed temperature, fluidizing velocity, excess air ratio for burning coal, primary to secondary air ratio remain the same for liquid fuels as that of coal except the fuel feeding system. Liquid bio oil produced from biomass using fast pyrolysis process can also be used .The temperature in the furnace of CFBC boilers is comparatively less with that of the conventional utility boiler which results as the outlet steam temperature in the super heater and reheater may not attain the temperature dictated by turbine inlet. Hence the solid particles and the flue gases are circulated so that the outlet temperature of the super heater and reheater can be increased. This survey paper highlights on aspects such as hydrodynamics, heat transfer and combustion related to CFBC boilers and their important design details.

Superior features of CFBC boiler - cold cyclone design

1. High efficiency (even at part loads) -low operating cost.
2. Wide fuel band -can burn coal, lignite, washery rejects, pet coke etc.

3. Simple fuel preparation -no grinding required
4. Low emission levels -due to staged combustion
5. Quick start up -due to cold cyclone design
6. Good load chasing ability -comparable to PF boilers
7. Low erosion risk -no bed tubes
8. Reduced maintenance -minimum refractory

CIRCULATING FLUIDIZED BED COMBUSTION BOILER AND VARIANTS IN



COMPONENT DESIGN

The gas velocity employed in a CFB is usually in the range 4.5 to 6 m/s. Air is fed to the unit as primary air, secondary air for fuel and limestone feed, air to the loop seal and fluidizing air to the ash classifier. The bottom ash classifier is designed to remove larger bed particles and recycle small particles back to the combustion chamber for improved heat transfer. The operating bed temperature is usually in the range of 850-900 °C, but in the case of low grade fuels the bed temperature can even be below 800 °C. The temperature ranges around 850°C optimizing the sulphur capture efficiency of limestone, combustion efficiency, NOx content and agglomeration of the bed material as well.

The flue gases from the cyclones goes to the back-pass of the boiler and the bed particles are re-circulated to the combustion chamber through fluidised bed heat exchangers. There are four such fluidised bed heat exchangers namely Super heater I, super heater II, evaporator, and reheater. The combustion chamber is enclosed with water-cooled tubes and a gas-tight membrane. The lowest part of the combustion chamber is refractory-lined. The boiler has two super heaters namely final super heater (FSH) and low temperature super heater (LTSH), a bank of economisers. The super heaters, economizer and air pre-heater are located in the back-pass. The flue gas goes through the back-pass to the electrostatic precipitator and, finally, flue gases are blown to the stack. Ash is removed from the bottom of the combustion chamber by the ash-drain system. The lime feeding system is used when sulphur capture is needed.

Design changes are introduced in the component levels in order to ease the operation, to enhance the performance or meet the regulatory compliance. The following paragraphs give an account of such design modifications as appeared in the literature. Design of CFBC includes the design of riser, cyclone separator, heat exchangers etc. The CFBC boiler has external heat exchangers and has two cyclone separators .Modification in the cyclone separator is made as the temperature profile is higher. The width of the cyclone inlet duct is reduced and the vortex finder is extended . Fluidizing nozzle modification (T-style) leads to pressure minimization. The performance of the CFBC boiler such as combustion efficiency, stability etc is improved by slightly modifying the cyclone separator, nozzle and ash reinjection system.

Li Zhao, Xiangdong Xu describes a new design model called "cell model method" and split the furnace into three regions and each region has different velocity. The regions are high velocity combustion region, low velocity heat transfer region and medium velocity suspension region. The differential velocity CFBC combustor improves the efficiency of the combustion. Circulation of bed material is by discrepancy of entrainment at differential air velocity. The velocity is in the order of 3-5m/s in the main bed and is 0.3 to 0.8 m/s in the additional bed.

A continuous stirred tank reactor model of CFBC has been proposed and in this model coal, limestone, ashes which are collected in the furnace are mixed and blown into the furnace by the primary air. This method is stable and is preferred during startup, shutdown operations and during abnormal conditions. Q. H. Li, Y. G. Zhang, A. H. Meng developed a novel model of CFBC called horizontal CFBC. It consists of primary, secondary combustion chambers, cyclone separator, heat recovery area, burnout chamber loop seal etc. Here the overall height of the boiler is reduced. The flow is a multi pass flow. The dilute zone comprises of upper part of primary furnace, secondary furnace and the combustion chambers whereas the dense zone is the lower part of the furnace. The solid entrained enters into the primary, secondary, third chamber, cyclone, loop seal etc and finally into the dense bed.

ADVANTAGES OF CFBC BOILERS OVER BUBBLING BED BOILERS

	Particulars	**Bubbling Bed**	**CFBC (Cold Cyclone)**	**Advantage for CFBC (Cold Cyclone)**
1.	Economic range	<60 TPH	60-500TPH	Lesser floor space requirement
	Type	2-pass	Tower	
2.	Thermal Eff. (Coal)	83%	87%	Better efficiency due to ash recirculation
	Carbon burn up	93%	98%	and longer reaction time in large furnace.
	Power consumption	~ 14 KW/MW (th)	~ 18 KW/MW (th)	Higher bed height of 1600mm vs. 1300mm.
	Fuel flexibility	Limited range	Wide range	Staged air, larger furnace volume, more
	Fuel preparation	<8 mm	<8 mm	residence time
	Fuel fines <1mm	<20%	<50%	No monsoon problems of feeder jamming &
	Fuel Moisture	~10-12%	~16%	coal pipes jamming
3.	Reliability	Low	Very High	No inbed tubes, No erosion problems
	Response	Poor	Very good	Equal to PF
	Auto Controls	Combustion control not possible	Possible	Stepless turndown upto 30% achievable.

4.	Fluidising velocity	2-3 m/sec	4-5 m/sec	Leads to more compact furnace
	Furnace Resi. Time	2-3 sec.	4-5 sec.	397
	Bed heat release	~1.5 MW/m	~5.0 MW/m	
5.	Bed Temp.	Falls at part loads	Constant	Much better part load efficiency
	Bed Temp. Control	In-bed tubes & bed partition	Ash recirc & staged combustion	Auto combustion control possible.
	Bed level control	Intermittent draining	Intermittent draining	No bed tube erosion

For a typical 300MWe CFBC boiler - with the basic components such as furnace, four cyclone separators - four double loop seal system is designed . Heat transfer coefficient is reduced along the furnace height. Similarly the heat transfer coefficient is more at the corners rather than the centre of water walls. Pneumatically operated external heat exchangers are developed to control the gas- solid flow in the CFBC. The main advantage is that the heat transfer in the external heat exchangers can be adjusted by means of height of the chamber. The air flow can also change the heat transfer rate. Also an empirical relation between mass flow rate of solids and its pressure drop has been obtained .

$$G_s = C_D\ 2\rho(1-\varepsilon_{mf})\ \Delta P_O \qquad \text{(i)}$$

CFBC boiler bottom ash has more physical heat. This heat is reclaimed [31] by means of a Fluidized bed ash cooler called CFBAC. This is applied to 300MW CFBC boiler. Experimental set up shows that the CFBAC had good particle flow characteristics. Fluidizing velocity and height of separation are the two important parameters in this design. This has good cooling effect and energy conservation.

Industrial CFBC‟s are operated at low operating pressures. Evaporation of water is more in CFBC‟s operating at low operating pressure. To avoid over heating of flue gas at furnace exit, the evaporator tubes are submerged. But the submerged tubes get affected by erosion. In order to alleviate the erosion to the submerged tubes, Evaporating Loop Seal (ELS) has been developed . ELS work at lower fluidization velocity and hence erosion is alleviated.

Internal recirculation-CFBC boilers are developed by Babcock and Wilcox and it has two stage impact solids separator namely the primary and the secondary stage. The secondary stage is multi stage dust collector. The main advantages as described by M.Maryamchik , Belin.F are high solid collection efficiency, controlled furnace temperature, high separator reliability etc. Feeding limestone leads to high sulphur retention. Fuel ash which is a combination of fly ash and bottom ash contains unburnt carbon particles and lime particles. Loffler et al., ; Hou et. al., proved that by injecting NH_3 at the entrance of the cyclone separator and circulating ashes significantly reduces the N_2O emission which is an important pollutant in CFBC boilers.

670t/h Solid – fuel combustion CFBC model with enriched oxygen described by J.Krzywanski et.al has two different conditions. Combustion in a gas mixture based on O_2 – N_2 and the other one without N_2 that is O_2-CO_2. The temperature in the bottom dense zone increases and hence enhanced heat transfer takes place in the oxygen enriched zone. CO_2 is more in the oxygen enriched CO_2 based gas mixture. Increase in CO_2 and decrease in CO leads to better efficiency. NOx is reduced in both the environments. This is one of the designs of CFBC boiler which yields better Heat Transfer Coefficient, better efficiency, lower emissions etc.

According to J.F. Li.et.al , the combustion of 300MWe CFBC boilers in China are unstable. Moreover slagging outside the furnace is more and cyclone separators are overheated. CFBC boilers with once through steam cycle has better efficiency when compared to the existing boilers as the CO_2 content is reduced . While using this, the evaporation and economizer duties are reduced and the superheat duty is increased. Evaporation duty is reduced when the lower furnace refractory lining is thickened and when the evaporator wing walls are removed. 10% of tubes looping of platen super heaters are added to increase the superheat duty. Oxy-fuel combustion is oxygen fired CFBC which has major reduction in CO_2. This is one of the Carbon capture and storage (CCS) technology. This has been described by Arto Hotta .

Different operational conditions such as excess air, bed operational velocity and particle diameter on bed temperature and the overall CO, NOx and SO_2 emissions from the combustor are investigated and are validated using 50 kW CFBC combustor and an industrial-scale 160 MW CFBC combustor which uses different types of coal. The effects of bed operational velocity and coal particle diameter on mean bed temperature and emissions of CO, NOx and SO_2 results have been investigated for three particle diameters (540, 651 and 852 μm) and for six bed operational velocity values (of about 4.15, 4.50, 5.00, 5.50, 6.00 and 6.50 ms^{-1}). Bed operational velocity has a more significant effect on CO emission than to bed temperature. Increasing excess air decreases SO_2 and NOx emissions. However, NOx emission increases with the operational bed velocity while SO_2 emission decreases.

The next important area of CFBC is controller design. Though all the fluidization types look similar, there exists some difference between them. PID controllers, fuzzy logic controllers are applied to CFBC by many authors. The main control loops in a CFBC boiler are: Steam pressure (boiler load) control, Flue gas O_2 content control, Combustion air distribution control, Drum level control, Superheated steam temperature control, Combustion chamber pressure control, Bed pressure control, SO_2 control.

II. Hydrodynamic Behavior And Heat Transfer Of CFBC

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The study of hydrodynamic behaviour leads to the understanding of gas- solid flow in the furnace under different operating modes. Hydrodynamics of solids are explained based on porosity or voidage of bed material, average gas velocity, mass flow rate of solid particles etc. Several authors have described the hydrodynamics of CFBC boilers in many ways. The hydrodynamics mainly depend on bed pressure drop; solid particles concentration, fluidization velocity and circulation rate of solid particles.

The bed pressure drop varies for circular and non circular bed and packed bed with fluidization height. During combustion process, due to collisions with inert bed particles, abration of char particles takes place and small particles of char separate from the main particles. This process is called attrition, and it depends on the coal type [45]. An understanding of solids suspension density both in axial and radial directions gives a better flow pattern which has an impact on heat transfer . The correlations for these attributes namely the bed pressure drop, solid particles suspension density, circulation rate of solid particles, fluidization velocity and their impact on heat transfer are given in table 1 and 2 respectively.

Yuen et al., Li et al., state that there exists a post combustion of solids and gaseous particles in the cyclone separator and is sensitive to coal type, and it is severe when a low volatile anthracite coal is burnt. The particle size distribution, primary to secondary air ratio and fluidizing air flow rate plays a major role in the post combustion. Jun Su, Xeroxing Zhao et.al. Have grouped the CFBC boiler based on the bed material. The effective material is the fine particles and ineffective material is the large material. The ineffective material remains in the bed while the fine particles are entrained out of the bed.

The heat transfer plays an important role in CFBC design. There exist three mechanisms for heat transfer. They are (i) fluid-to-particle heat transfer (ii) particle-to-fluid heat transfer and (iii) bed to wall heat transfer.

Gas to particle heat transfer coefficient can be calculated using the Nusselt‟s relation,

$$N_u = 1.6 \times 10^{-12} (R_e / \varepsilon)^{1.3} P_r^{0.33}$$

The above correlation must be added to the radiative coefficient to obtain the overall heat transfer coefficient. By neglecting the heat radiation and convection in the dilute phase, a simpler empirical correlation for the overall heat transfer coefficient to the water wall of a CFBC presented is given by

$$h = 5^{0.391} \quad {}_{0}.408$$

The overall heat transfer coefficient from bed to wall at the bottom dense zone is given [8] as

$$h = 40(\rho_b)^{1/2}$$

where ρ_b is given by $\rho_b = \rho(1\text{-}\varepsilon) + C\,\varepsilon$

Heat transfer from bed material to wall tube is given by

$$Q_{bw} = hA_w\, T_b - T_w$$

III. Conclusion

Description on a typical circulating fluidized bed combustion boiler and narration on the design changes which are introduced in the component levels in order to ease the operation, enhance the performance and to meet the regulatory compliance are given. In addition, salient correlations related to hydrodynamics, heat transfer and combustion are provided. Mathematical modeling and simulation has been an effective tool in analyzing and optimizing the performance and diagnosing the faults. It is believed that this paper will be of use for control and system engineers to model CFBC boiler to analyze the plant performance during normal and abnormal situations and assess the efficacy of different control schemes to meet the performance criteria desired by the plant owners and operators. New technology involves at around 400 C, result in short - up and shut down time. Low emission values. Low ash recirculation rates and low dust load in combustor, preventing erosion.

IV. Acknowledgement

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References

[1] Grace, J. R., Heat Transfer in Circulating Fluidized Beds,"In Circulating Fluidized Bed Technology I", P. Basu (Eds.), Pergamon Press, Oxford, 63 – 72,1986.

[2] Raiko, R., Kurki-Suonio, I., Saastamoinen, J., & Hupa, M., "International Flame Research Foundation (IFRF)", Jyväskylä, 417-466, 1995.

[3] Kunii, D., Levenspiel, O.," Fluidization engineering". Butterworth-Heinemann, Boston, USA, 1991.

[4] Basu, P., Subbarao, D., An experimental investigation of burning rate and mass transfer in a turbulent fluidized bed, "Combust. Flame" 66, 261-269, 1986.

[5] Basu, P., & Fraser, SA., Circulating fluidized bed boilers–design and operations. Butterworth- Heinemann, Boston, 1991.

[6] Waqar Ali Khan, Khurram Shahzad, and Niaz Ahmad Akhtar, Hydrodynamics Of Circulating Fluidized Bed Combustor: A Review, "Journal of Pakistan Institute of Chemical Engineers", Vol. XXXVII, 1999.

[7] Bo Leckner, Fluidized Bed Combustion Research And Development In Sweden – A Historical Survey, "Thermal Science:" Vol. 7 ,No. 2, Pp. 3-16, 2003.

[8] Basu, P., and Nag, P.K., Heat Transfer to the Walls of a Circulating Fluidized Bed Furnace A Review, "Chem. Eng. Science", 51 (1), 1 – 26, 1996.

[9] Miccio.M., Miccio.F., Fluidized Combustion Of Liquid Fuels: Pioneering Works, Past applications, Today's Knowledge And Opportunities, "Proceedings of the 20th International Conference on Fluidized Bed Combustion",2009.

[10] Yrjo Majanne, Jani Laine, Jyri Kaivosoja, Petri Koykka, Modeling and simulation of interconnected CFB-boiler and fast pyrolysis processes – Control design case, 18th IFAC World Congress Milano (Italy), August 28 – September 2, 2011

[11] Sivakumar L,Sundarraj S,Anandhi,T, System design document - Software on dynamic modeling of CFBC furnace, "An Internal consultancy project" document prepared at Sri Krishna College of Engineering and Technology , Coimbatore and submitted to Corporate, R & D, BHEL, Hyderabad, India, 2010.

[12] Wang, Q., Zhonggyang Luo, Xuantian Li, Mengxiang Fang, Mingjiang Ni, Kefa Cen, "Energy" 24(1999) 633-653, 1999.

[13] Jong-Min Lee, Jae-Sung Kim, Jong-Jin Kim, CCT experience of Tong-Hae CFB boiler using Korrean Anthracite, "03 APEC Clean fossil energy technical and policy seminar", Korea, 2003.

[14] Li Zhao, Xiangdong Xu, A mathematical model for differential-velocity Circulating Fluidized Bed Boiler, "Journal of Thermal Science" , Volume 8, No.3, 1999.

[15] Xu Zhengyu, Niu Kai, The simulator model for a circulating fluidized bed boiler, "Computers and Applied Chemistry", vol - 02, 2008.

[16] Li, Q. H., Zhang, Y. G., Meng, A. H., Design and Application Of Novel Horizontal Circulating Fluidized Bed Boiler, "Proceedings of the 20th International Conference on Fluidized Bed Combustion", 2009.

[17] Sung won kim, Won Namkung and Sang Done kim, Solids flow characteristics in loop seal of a circulating fluidized bed, "Korean journal of Chemical Engineering", 16(1),82-88, 1999.

[18] Basu, P., Cheng, L., An Analysis of Loop Seal Operations in a Circulating Fluidized Bed, "Transactions of Institution of Chemical Engineers", v. 78, Part A, pp 991 – 998, , Oct 2000.

[19] Malcus.S., Chaplin, G., Pugsley, T., The hydrodynamics of the of the high density bottom zone in a CFB riser analyzed by means of electrical capacitance tomography, "Chemical Engineering science", 55, 4129 – 4138, 2000.

[20] Animesh Dutta, Prabir Basu, An experimental investigation into the heat transfer on wing walls in a circulating fluidized bed boiler, "International journal of heat and mass transfer", Volume 45, Issue 22, Pages 4479-4491, 2002.

[21] Lee,J.M., Jae sung kim, Jong Jin Kim, Evaluation of the 200 MWe Tonghae CFB boiler performance with cyclone modification, "Energy",28,575-589, 2003.

[22] Yang, H. R, Yue, G. X., Wang, Y., "Journal of Engineering for Thermal Energy and Power", 20(3),291-295,2005.

[23] Jin, X., Lu, J. F., Qiao, R., et al., "Clean Coal Technology", 5(1): 20-23, 1999.

[24] Yue, G. X., Lu, J. F., Zhang, H, et al. Design Theory of Circulating Fluidized Bed Boilers, "18th International Fluidized Bed Combustion Conference", May 18-21, Toronto Canada, 2005.

[25] Anusorn chinsuwan, Animesh Dutta, An investigation of the heat transfer behavior of longitudinal finned membrane water wall tubes in CFBC boilers, "Powder technology" , 193, 187-194, 2009.

[26] Jun Su, Xiaoxing Zhao, Jianchun Zhang, Aicheng Liu , Hairui Yang, Guangxi Yue, Zhiping Fu, Design and Operation Of CFB Boilers With Low bed Inventory, "Proceedings of the 20th International Conference on Fluidized Bed Combustion", 2009.

[27] Zhang, P., Lu, J. F., Yang, H. R., Zhang, J. S., Zhang, H., Yue, G. X., Heat Transfer Coefficient Distribution In The Furnace Of A 300MWe CFB Boiler, "Proceedings of the 20th International Conference on Fluidized Bed Combustion",2009.

[28] Zhang Man, Bie Rushan, Yu Zezhing, Jiang Xiaoguo, Heat flux profile of the furnace wall of a 300 MWe CFB boiler, "Powder Technology", 203,548-554,2010.

[29] Xiong.B., Xiaofeng Lu, R.S.Amano, Hanzhou Liu,Gas-solid flow in an integrated external heat exchanger for CFB boiler, "Powder Technology",202,55,61,2010.

[30] Jones, D.R.M., Davidson, J.F., The flow of particles for a fluidized bed through orifice, "Acta4",180-192,1965.

[31] Bing zeng, Xiaofeng xu, Lu gan, Maolong Shu, Development of a novel fluidized ash cooler for CFB boilers: Experimental study and application, "Powder technology", 212, 151-160, 2011.

[32] Xuanyu Ji, Xiaofeng Lu, Xiaolei Xue, Honghao He, Wang,Q., Jianbo Li, Development On A Small Scale Industrial CFB Boiler With An Evaporating Loop Seal, "Applied Thermal Energy", 36, 464-471, 2012

[33] Maryamchik, M., Wietzke,D.L., B&W PGG IR – CFB: Operating experience and new developments, "21st International; Fluid Bed Combustion Conference", Italy,2012.

[34] Belin,F., Marymchik, M., Walker, D.J., Wietzke, D.L., Babcock & Wilcox CFBC boilers- Design and experience, "16th International Conference on FBC", 2001

[35] Loffler., Wartha, C., Winter, F., and Hofbauer, H., "Energy & Fuel", 12:1024-1032, 2002.

[36] Hou, X. S., Zhang, H., Yue, 0. X, et al., Reduction of N20 and NO by NH3 on Circulating Ashes: The Effect ofO2 Concentration, "19th International Fluidized Bed Combustion Conference", Austria, Vienna, 2006.

[37] Krzywanski .J., Tomasz czakiert, Waldemar muskala, Robert secret, Wojciech Nowak, Modeling of solid fuel combustion in oxygen-enriched atmosphere in CFBC, "Fuel processing Technology", 91, pages 364-368, 2010.

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